Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 91 (2020) 478–485

www.elsevier.com/locate/procedia

30th CIRP Design 2020 (CIRP Design 2020)

Real Time Internet of Things (IoT) Based Water Quality Management System

Saif Allah H. AlMetwally [a], Mohamed K. Hassan [b], Mohamed H. Mourad [c]

Industrial and Management Engineering Department, Arab Academy for Science, Technology & Maritime Transport, Abu-Qir Campus – P.O. Box 1029 Alexandria – Egypt

[a] Elibrahimia – Bab Shaarqy, Alexandria, Egypt Tel.: +2-0128-666-0806. E-mail address: saif.almetwally@live.com

[b] AASTMT, Abu-Qir Campus Alexandria, Egypt Tel.: +2-0102-588-5850. E-mail address: mkhassan@aast.edu

[c] AASTMT, Abu-Qir Campus Alexandria, Egypt Tel.: +2-0102-000-6826. E-mail address: mmourad@aast.edu

Abstract

The rapidly transforming technologies and changing of people's expectations triggered the fourth industrial revolution, commonly referred to as Industry 4.0. Water is the core resource and a vital for life of all species, as it is a limited resource that needs to be utilized efficiently. Monitoring various aspects of the water quality leads to a clear understanding of the aspects that should be considered for a healthy life and to avoid wastage of water. Using Internet of Things (IoT) should allow for the integration of real time monitoring and controlling of water quality. The suggested system utilizes Internet of Things (IoT) through using sensors to measure the water quality factors such as (pH, temperature and turbidity) for home applications. The system should allow for autonomous decision making for controlling the water quality factors such as (acidity, alkalinity, temperature and amount of total suspended solids expressed by cloudiness or haziness) measured by mentioned sensors within the acceptable limits and keeping records of the historical readings on a cloud based platform. The system will lead to real time data acquisition, transmission and processing of water quality data. This will give the ability to automatically react to the changes in the system outputs. Using Internet of Things (IoT) means the system can be accessed from anywhere through Internet, for example through a mobile application remotely. The objective of the system is to allow the water consumer in home to be able to judge the quality of the incoming water and to control it to the required levels. The system also utilizes the different filters used in home to enhance the water quality in an efficient way. As the filters will only be used once needed and not all the time. Utilizing such, a system should lead to improving the public health and the cost of controlling the quality of the consumed water. The system should eliminate the inconvenient and lengthy off line lab analysis of collected water samples. The system should provide a user-friendly interface with infographics and meters to illustrate the quality factors as Lower-Upper limits and the acceptable values. In addition, the system should provide an easy way for the configuration of the controllers and the communication with the sensors.

Keywords: Industry 4.0; Internet of Things (IoT), Water Quality, Smart System

10.1016/j.procir.2020.03.107

1. Introduction

Technologies are rapidly developing which leads to a tremendous transformations and effects on the daily life of mankind. Human beings are forced to change the way they think and to develop new means of doing things, which is leading to the fourth industrial revolution, referred to as Industry 4.0.

The technologies that are being introduced allow the machines to be smarter and easily accessible from any location. This is supposed to lead to more efficient and productive activities. The ability to share information and keep historical records through the applications of Internet of Things (IoT) should enable the analysis of trends leading to the avoidance of future unexpected problems.

There are a lot of applications and areas that have applied the principles and models of the Industry 4.0. The models can be adopted to typically any system that has the Internet of Things (IoT) capabilities. The Internet of Things (IoT) calls for the use of a cloud environment to communicate, store data and connect different devices. The devices could be in different places connected through networks using the developed capabilities of wireless communication.

The Integration of the different types of devices and sensors enable the data collection. The data is then processed enabling the system to make decisions based on the already loaded decision rules. This allows the exploration of new opportunities, for example improving the sustainability of environmental resources, such as water in our case.

The ability to control and manage this valuable resource efficiently will hugely affect the life cycle of the water system. To be able to collect the water quality data wirelessly in real time makes it easier to control such quality based on the consumer preferences. In addition, to further judge the water quality at different seasons of the year.

The suggested system should enable the optimization of the efforts and cost spent on the manual data collection and the logistics of sending the samples to chemical labs for processing. Not only that, but the results coming from the labs will be old and after the fact data. As by the time the analysis results are available, most probably the inlet water characteristics have changed. Allowing the ability of real time monitoring should enable the uphold of the water quality at the present levels required by the application.

This paper starts with introduction then topics are covered through the sections of the literature review. The paper discusses the industrial revolution and then the development of the smart systems to monitor the water quality. The paper also introduces different Internet of Things (IoT) applications and areas of interest and the previous similar work. Then proposed system architecture and its components are laid out. The design diagrams of the proposed system are also shown. Finally, the expected model outcomes, opportunities for future work and conclusions are listed.

2. Literature Review

2.1. Industrial revolutions

The first industrial revolution was introduced around the 18^{th} century and was mainly focused on the usage of steam power in manufacturing, this was the first transition point from using human labor in production and replacing it with machines [1].

After that, the second industrial revolution introduced mass production lines in order to produce many non-customized products around the 20^{th} century, following it, the third industrial revolution involved the usage of computer technologies and automation of the production activities around the 1970s [2].

Now and because of the previous evolutions, humans are going through the most advanced and smart industrial revolution of them all. This is a result of the continuous improvements and developments mankind has lived through the history. The efforts aiming to maximize productivity and efficiency [3].

Introduced the main components of the Industry 4.0 as Internet of Things (IoT) and big data analytics. The Internet of Things (IoT) is a network of different components consisting of sensors, controllers and software, all connected together in order to exchange data efficiently [4].

The development of computer systems and electronics, created a seamless link between different devices [5]. This provided the ability of the continuous exchange of data which defines the Internet of Things (IoT) [6].

The use of Internet of Things (IoT) is becoming a vital need in different industries such as the health care sector, which expands the doctor ability to diagnose the patients. This enables the doctors to interact quicker and save the medical checkup cost, time lost and to keep a close medical history monitoring of the patient remotely [7].

In the food supply ecosystems, the Internet of Things (IoT) affects the industries in different stages such as production, distribution, storage, consumption and waste disposal. This will lead to best allocation of food supply chains to reduce the process inefficiencies [8].

Efforts was spend on applications to use internet of Things (IoT) to remote-sensing the local data to be able to analyze the water resources remotely [11].

Cyber Physical Systems, Internet of Services and Smart Factory [9], are advances aiming to allow the machines to evolve, become smarter and to communicate with each other in different places through the internet. This enables the machines to have the capability to analyze the data collected and then react accordingly for example to avoid production interruptions [10]. The industrial revolutions overview is shown in Figure 1.

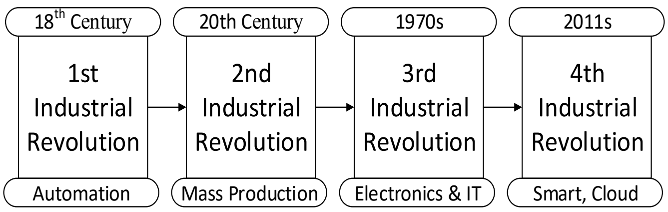

Figure 1. Industrial revolutions overview.

2.2. Water Resource

Water is a limited resource and due to the issue of climate change the planet earth is facing, the challenge is becoming much more difficult to manage. This valuable resource needs to be consumed efficiently and to be conserved for future generations. Also to keep in mind that the demand on water is increasing as it is a vital need for all creatures to stay alive and perform all their activities [4].

In the same time it's important to make sure that water resources are always healthy and consumable in the face of the rapidly growing industrial and agricultural activities which affect water pollution greatly due to the generated waste and the leakage of chemicals [11].

The vast majority of the community does not understand the critical situation that humanity is facing at the moment. The world continues to waste the water by inefficient usage as water is poorly allocated. This is due to a lack of understanding of the efficient water management concepts [12].

The monitoring of the chemical components of water is necessary in order to avoid any quality problems caused by water consumption of various activities [13].

Introducing a smart meter controller that displays the exact amount of water used and communicating the data directly to the water city network will eliminate the human error factor in manual reading of the consumptions. This will furthermore get rid of the cost of human labor used in this process, as this will allow the utilization of water efficiently. Avoiding any shortages in the resource caused by the uncertain consumptions patterns that might occur is also an objective of such a system [14].

Such a system can become handy in countries like China as the rapid development of the community and the distribution of the freshwater geographically can cause water shortage. In the same time the pollution problem expands to more amounts of water [15].

The ability to gather relevant data of water quality factors and exchange them remotely by the integrations of Internet of Things (IoT) technologies in various environments such as early indicators of the disaster in order to manage it well, also the water sustainability by monitoring and controlling [17].

Drinking water is commonly stored in tanks found on the top of the buildings. These tanks supply each apartment in the building through pipelines. Some diseases could come from the old pipping system, which may release containments in the water while it flows inside it. In addition, the water that stays stagnant in the tanks may give rise to bacterial contamination.

In some cases, especially in the developing countries, the water that supplies the tanks itself may not be up to the standards of the drinking water. All of this leads to a serious need for a real time monitoring system that can collect and analyze the data and give a clear indication of the current status of water quality. This can avoid further health problems within the building that could expand to the whole community [16].

The characteristics of the water quality can be divided into three different categories. Firstly, physical such as temperature, turbidity, chromaticity, smell, color and electrical Conductivity). Secondly, chemical such as pH, Dissolved Oxygen "DO", Chemical Oxygen Demand "COD", Biochemical Oxygen Demand "BOD", Total Organic Carbon, Heavy Metal ion, and nonmetallic Poisons. Thirdly, is Microbiological, including Total Bacteria, and Total Coliforms [15].

In Egypt, there is a major challenge the country is facing regarding water, as it is becoming very limited resource. This resource needs a lot of development in order to keep up with the continuous growth of demand due to the rapid population growth. Given that the main source of water is the Nile River and Egypt's share of its water is limited to 55.5 billion m^3 per year and the levels are decreasing each day. There is an increasing need to utilize each water drop and to reduce the wastage to the lowest levels possible in order to be able to conserve water for the future [17].

2.3. Smart water quality management system and Internet of Things (IoT)

The quality of water is affected by the variety of human industrial activities that directly impact the drinking water being distributed to homes through the city water network. Chemicals used in farming also contaminate underground water. Even the air contains a huge number of particles which plays a large role in the pollution of the water cycle on earth [18].

In order to be able to control the quality of the drinking water, it is necessary to be familiar with the factors to be monitored. The usage of enhanced history logging sensors can enable a good way for managing such factors [19].

Building a smart water quality monitoring system based on the Internet of Things (IoT) technologies requires integration of different components. The components can monitor and control the water quality in real time [4].

One of the applications that the Internet of Things (IoT) can be used in, such a system can support the life activities on many domains such as homes and offices through the transportation and management of the resource [20].

There are previous efforts spent in the scope of monitoring the water quality but without much consideration to any actions when the water quality indictors go out of the accepted limits. Some of these efforts used Internet of things (IoT) platform to store and view the data gathered from different locations on the controller [21].

Another system did introduce a new business model to control and optimize the resources remotely. The system tracks the water characteristics, allowing for continuous improvement and monitoring of the data. This leads to increasing the efficiency of water monitoring. Combining the cloud computing and Internet of Things (IoT) technologies allowed the exploration of a wide set of applications that state the importance of cloud for any Internet of Things (IoT) system [22].

Other proposed systems which monitor the level of the water in real time uses the minimal energy consumption possible and the mobile network to send notifications through SMS by controllers [23].

Another system that monitors the quality of water remotely uses low power sensors on many nodes that feed a central base with all the gathered data. Then comparing it with the standard values and sending an automated warning SMS to each node [24].

Another system provided a low power model that is used to gather the water quality data based on Internet of Things (IoT) technologies. The system then sends alerts to the remote user if any values do vary from the standard values already loaded on the program [25].

Some systems used Bluetooth technology to communicate with the controller however that had a disadvantage as there was signal drops leading to some missing data sets [26].

Other proposed system design will provide the ability to warn the consumer of the excess water use. This will be provided by automated water utilization monitoring system in every water outlet in the house, that will lead to detailed view of the water bills combined [19].

Additionally, proposal of an Internet of Things (IoT) based water monitoring system that measures water levels instantons, considering it as important factor to avoid water flood that effects disaster prone areas [5].

Followed by, a system that check the water factors in the tanks and then decide if it is suitable for consumption upon the water quality parameters measured [27].

Finally, a continuous water monitoring system of river using wireless sensors in order to measure and send the data to a base to simulate and evaluate the quality of water [28].

The objective of the proposed system in this paper is to allow the integration of water quality monitoring sensors that are commonly available in the local market to detect water factors in real time. The system also utilizes the different filters used to enhance the water quality in an efficient way. As the filters will only be used once needed and not all the time. Utilizing such, a system should lead to improving the public health and the cost of controlling the quality of the consumed water. The system should eliminate the inconvenient and lengthy off line lab analysis of collected water samples.

The model proposed aims to combine water quality sensors (pH, temperature and turbidity), water distribution sensors (ultrasonic water level and flow) and the microcontroller (arduino uno) to capture the data and process it in order to execute the commands to other components of the system.

The interface and the mobile application is a real time monitoring and control tool that can be used to monitor the factors performance, and this will pave the way for the water distribution system in the building to monitor the quality of water consumed.

Also the ability to warn and avoid the consuming of unaccepted water depending on the measured factors to be consumed in the home to avoid any health issues could occur.

3. System Architecture

3.1. Sensors

3.1.1. Temperature Sensor

The temperature sensor is used to monitor the coldness or hotness of the water, measured in degree Celsius, with precision of 0.1 steps, which is more accurate than the mercury thermistor.

The operation temperature range varies between -55 to 150, in this case the water degree is maintained between 25 to 30 degree Celsius , which this is the ideal temperature for human body usage [28]. The sensor is shown in Figure 2.

Figure 2. Temperature Sensor.

3.1.2. pH Sensor

The pH sensor is used to monitor the acidity and alkalinity in water, it is designed to give a value from 0 to 14 according to the hydrogen ions concentration with the negative logarithmic, in this case the water pH is maintained between 6 to 8.5, which this is the acceptable limits for the human body to be consumed [29]. The sensor is shown in Figure 3.

Figure 3. pH Sensor.

3.1.3. Turbidity Sensor

The Turbidity sensor is used to measure the cloudiness or haziness of the water, which is due to the amount of particles in water invisible to human eyes.

The sensor uses light to detect suspended particles in water by calibrating the light transmittance and scattering rate and it changes with the water quality of total suspended solids (TSS), The acceptable value measured for human body from 0 to 5 NTU [27].

The factor that this sensor measure can be controlled by the filters, to avoid health issues due to the high rate of the suspended solids (TSS) in water[29]. The sensor is shown in Figure 4.

Figure 4. Turbidity Sensor.

3.1.4. Ultrasonic water level Sensor

The ultrasonic water level sensor is used to send pulses of sound waves to the water surface on the tank and receive them back in order to calculate the water level in the tank, to avoid the over flow from the water inlet and to determine the water volume in the tank. The sensor is shown in Figure 5.

Figure 5. Ultrasonic Sensor.

3.1.5. Water Flow Sensor

The water flow sensor is used to measure the amount of water that will pass through the outlet of the system, as every rotational of the internal pinwheel the rotor sends an electrical pulse that will translate to a water volume. The sensor is shown in Figure 6.

Figure 6. Flow Sensor.

3.2. Auxiliaries

3.2.1. Solenoid water valve

The Solenoid water valve is used to control the water flow in order to change the water flow to the filters or not, according to the received command from the controller. The valve is shown in Figure 7.

Figure 7. Solenoid Water Valve.

3.2.2. Water Filters Unit

The water filter unit is used to treat the water passed through with the different stages. The filter cartridges is shown in Figure 8.

Firstly, the micro sediment cartridge, that removes impurities, rust, dust, dirt, mud and sand, which effects the taste and appearance of the water.

Secondly, the carbon cartridge that remove chlorine, chloramines and condition the water, which effects the odor of the water.

Thirdly, the reverse osmosis membrane that remove organic and inorganic compounds such as fluoride and also impact the total dissolved solids (TDS) from the water to reduce arsenic, lead, parasitic and copper.

Figure 8. There Stages Water Filter Cartridges.

3.3. Controller

The controller will be responsible for storing and retrieving numerical data gathered from the sensors. Arduino Uno is preferred over Raspberry Pi 3 to avoid the communications problems from the added-on Wi-Fi module[9], Raspberry Pi 3 has process power of 1.2 GHz BCM2836 quad-core ARM Cortex-A7, Memory of 1GB RAM [30]. Arduino Uno is more cost efficient and have the ability to monitor the sensor readings and also give the commands [27]. The Arduino Uno controller is shown in Figure 9.

Figure 9. Arduino UNO.

3.4. Software

The Software proposed aim to present all the data collected from the different sensors, and store it on a cloud based platform that can be accessed remotely in order to control the system.

The mobile application is the most applicable interface as the mobile phones are widely available [18]. Also the usage of the expanded capabilities of the graphical interface on the mobile phone [28].

3.5. Block Model Diagram

In this section, an illustration of all the connected sensors of the model and the values of the sensors are gathered and stores on the controller. Then the Internet of Things (IoT) components will be able to take the decision upon the real-time values and record the trends based on the historical data recorded according to the turbidity values to determine if the water should flow in the filter or not. The proposed system block diagram is shown in Figure 10.

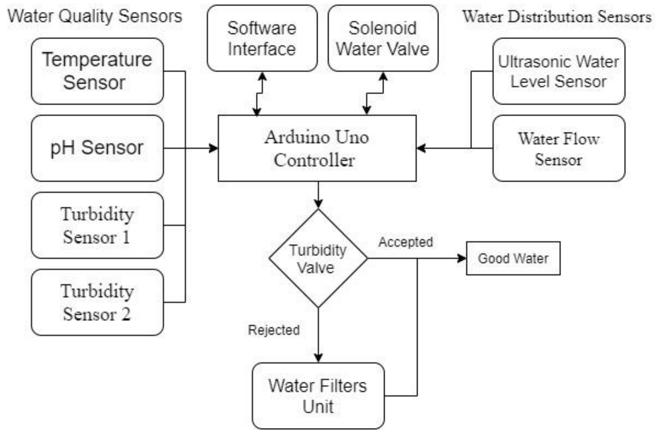

Figure 10. Proposed Block Model Diagram.

3.6. Model Algorithm

The proposed hypothesis is to connect the model on water inlet and gather the (pH, Temperature and the Water Level) readings and monitor the flow of water.

Hence, the first turbidity sensor sends the value to the controller to compare the value with the second turbidity sensor, at this stage, the control logic will take the decision either to open or close the valve so that the water flow to the filters or not.

Then the treated water will be stored in the second tank to be consumed safely. The proposed model algorithm is shown in Figure 11.

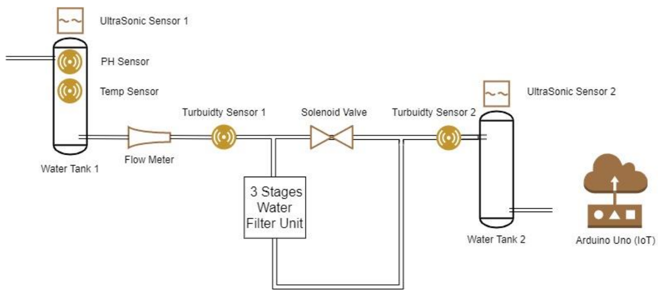

Figure 11. Proposed Model Algorithm.

4. Results and Discussion

This model intended to increase the efficiency of water management systems. In addition, the real time monitoring and operational activates limit the human error, followed by a prototype in order to validate the idea by collecting data and analyze it.

5. Conclusion

The introduction of an efficient smart water quality monitoring system, aims to eliminate the cost of the water samples analysis at off line lab.

In addition, giving a clear indication of the water quality factors to avoid any diseases effects public health and the cost of controlling the quality of the consumed water.

This system support the concept of a smart city that does not require human interactions and reduce the labor and operation costs. also utilizes the different filters used to enhance the water quality in an efficient way. As the filters will only be used once needed and not all the time.

In addition, the limitation to keep this system a low cost model to spread widely in different areas of interest.

6. Future Work

The implementation of the proposed system aim to enable the water management system to be autonomously driven, which leads to a smart building.

Expanding and ability to connect the different buildings in the city to one network, and continuously monitor the water quality and consumptions in different area, in addition, investigate the causes that changes water quality and adjust them immediately.

7. Acknowledgment

This paper wouldn't have had been resulted into successful completion without the valuable guidance of Prof. Mohamed K. Hassan and Prof. Mohamed H. Mourad on Department of Industrial and Management Engineering, Arab Academy for Science, Technology & Maritime Transport.

8. References

[1] A. Rojko, "Industry 4.0 concept: Background and overview " *Int. J. Interact. Mob. Technol.*, vol. 11, no. 5, pp. 77–90, 2017.

[2] Y. Lu, "Industry 4.0: A survey on technologies, applications and open research issues," *J. Ind. Inf. Integr.*, vol. 6, pp. 1–10, 2017, doi: 10.1016/j.jii.2017.04.005.

[3] M. Crnjac, I. Veža, and N. Banduka, "From concept to the introduction of industry 4.0," *Int. J. Ind. Eng. Manag.*, vol. 8, no. 1, pp. 21–30, 2017.

[4] P. Doss, "Smart Water Conservation and Management System Using IOT," vol. 7109, pp. 9–12, 2018.

[5] T. Perumal, M. N. Sulaiman, and C. Y. Leong, "Internet of Things (IoT) enabled water monitoring system," *2015 IEEE 4th Glob. Conf. Consum. Electron. GCCE 2015*, no. April, pp. 86–87, 2016, doi: 10.1109/GCCE.2015.7398710.

[6] J. H. Nord, A. Koohang, and J. Paliszkiewicz, "The Internet of Things: Review and theoretical framework," *Expert Syst. Appl.*, vol. 133, pp. 97–108, 2019, doi: 10.1016/j.eswa.2019.05.014.

[7] B. Farahani, F. Firouzi, V. Chang, M. Badaroglu, N. Constant, and K. Mankodiya, "Towards fog-driven IoT eHealth: Promises and challenges of IoT in medicine and healthcare," *Futur. Gener. Comput. Syst.*, vol. 78, pp. 659–676, 2018, doi: 10.1016/j.future.2017.04.036.

[8] R. Accorsi, M. Bortolini, G. Baruffaldi, F. Pilati, and E. Ferrari, "Internet-of-things Paradigm in Food Supply Chains Control and Management," *Procedia Manuf.*, vol. 11, no. June, pp. 889–895, 2017, doi: 10.1016/j.promfg.2017.07.192.

[9] G. Erboz, "HOW TO DEFINE INDUSTRY 4 . 0 : The Main Pillars of Industry 4 . 0," no. July, 2018.

[10] B. Tjahjono, C. Esplugues, E. Ares, and G. Pelaez, "What does Industry 4.0 mean to Supply Chain?," *Procedia Manuf.*, vol. 13, no. January, pp. 1175–1182, 2017, doi: 10.1016/j.promfg.2017.09.191.

[11] M. B. Kawarkhe and S. Agrawal, "Smart Water Monitoring System Using IOT at Home," vol. 21, no. 1, pp. 14–19, 2019, doi: 10.9790/0661-2101021419.

[12] J. M. Sudhakar, "International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES) AN IOT BASED SMART WATER MONITORING SYSTEM AT HOME," vol. 3, no. 11, pp. 60–67, 2017.

[13] D. G. R, M. N. S Khadri, and J. N. Kalshetty, "Smart Water Quality Monitoring System Using Iot Environment," *Int. J. Innov. Eng. Technol.*, vol. 10, no. 4, pp. 74–78, 2018, doi: 10.21172/ijiet.104.12.

[14] J. Joseph, K. M. Manju, M. R. Sajith, S. Nair, V. P. Viay, and S. Krishnan, "Water Management System Using IoT," pp. 4–7, 2018, doi: 10.15662/IJAREEIE.2016.0505080.

[15] X. Wang and W. Yang, "Water quality monitoring and evaluation using remote-sensing techniques in China: A systematic review," *Ecosyst. Heal. Sustain.*, vol. 5, no. 1, pp. 47–56, 2019, doi: 10.1080/20964129.2019.1571443.

[16] S. K. Ahmed Sha, S. Sankari, and A. Professor, "Smart Tank Water Monitoring System using IOT Cloud Server at Home/Office," *Int. J. Eng. Sci. Comput.*, vol. 8, no. 4, pp. 16748–16751, 2018.

[17] M. A. Ashour, S. T. El Attar, Y. M. Rafaat, and M. N. Mohamed, "Water Resources Management in Egypt," *J. Eng. Sci.*, vol. 37, no. 2, pp. 269–279, 2009.

[18] T. Sugapriyaa, "Smart Water Quality Monitoring System for Real Time Applications," *Int. J. Pure Appl. Math.*, vol. 118, no. 20, pp. 1363–1369, 2018.

[19] A. Aleksic, N. Ljepava, and M. Ristic, "Smart Technologies and Innovation for a Sustainable Future," *Smart Technol. Innov. a Sustain. Futur. Adv. Sci. Technol. Innov.*, no. January, pp. 333–338, 2019, doi: 10.1007/978-3-030-01659-3.

[20] L. Atzori, A. Iera, and G. Morabito, "The Internet of Things: A survey," *Comput. Networks*, vol. 54, no. 15, pp. 2787–2805, 2010, doi: 10.1016/j.comnet.2010.05.010.

[21] R. Ramya, "IEEE International Conference on Circuit, Power and

Computing Technologies, ICCPCT 2015," *IEEE Int. Conf. Circuit, Power Comput. Technol. ICCPCT 2015*, 2015.

[22] A. Botta, W. De Donato, V. Persico, and A. Pescape, "On the integration of cloud computing and internet of things," *Proc. - 2014 Int. Conf. Futur. Internet Things Cloud, FiCloud 2014*, no. December, pp. 23–30, 2014, doi: 10.1109/FiCloud.2014.14.

[23] A. Engineering, B. Vidya, K. Poonam, G. Priyanka, D. Gaurav, and P. A. S. Chandgude, "Water Level Monitoring System In Real Time Mode Using WSN," *Int. J. Emerg. Technol. Adv. Eng.*, vol. 6, no. 9, pp. 212–214, 2016.

[24] E. Ragavan, C. Hariharan, N. Aravindraj, and S. S. Manivannan, "Real time water quality monitoring system," *Int. J. Pharm. Technol.*, vol. 8, no. 4, pp. 26199–26205, 2016, doi: 10.15680/ijircce.2015.0306016.

[25] S. Geetha and S. Gouthami, "Internet of things enabled real time water quality monitoring system," *Smart Water*, vol. 2, no. 1, pp. 1–19, 2016, doi: 10.1186/s40713-017-0005-y.

[26] M. Joseph Vishal Kumar and K. Samalla, "Design and development of water quality monitoring system in IOT," *Int. J. Recent Technol. Eng.*, vol. 7, no. 5, pp. 527–533, 2019.

[27] A. Jain, A. Malhotra, A. Rohilla, and P. Kaushik, "Water Quality Monitoring and Management System for Residents," *Int. J. Eng. Adv. Technol.*, vol. 9, no. 2, pp. 567–570, 2019, doi: 10.35940/ijeat.b3521.129219.

[28] M. S. U. Chowdury *et al.*, "IoT based real-time river water quality monitoring system," *Procedia Comput. Sci.*, vol. 155, pp. 161–168, 2019, doi: 10.1016/j.procs.2019.08.025.

[29] D. JIAO and X. LUO, "Water Quality Monitoring System Based on LoRa," *DEStech Trans. Comput. Sci. Eng.*, vol. 10, no. iece, pp. 1107–1116, 2018, doi: 10.12783/dtcse/iece2018/26605.

[30] C. Paper, "Available Online at www.ijarcs.info AN IOT-BASED WATER SUPPLY MONITORING AND CONTROLLING SYSTEM," vol. 9, no. 3, pp. 202–206, 2018.